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FINAL REPORT

NASA Grant NAG5-262
prepared by
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1. Introduction

This report covers the IUE-related research of Professor R. J. Dufour during the period of NASA grant NAG5-262: from 1982 August 1st to 1994 September 30th. The research during the first ten years of this grant has been summarized in numerous interim reports submitted during that decade; therefore, herein I will concentrate on research and publications during the past two years, or that related to the 15th and 16th episodes of the IUE Observatory.

For the record, prior to 1992, Dufour was PI or a Co-I on 20 approved IUE programs, resulting in 20 publications –primarily in refereed journals. The programs and publications have been described in the various interim reports. In addition to these, Dufour has supervised students who have used IUE data in four M.S. and two Ph.D. degree theses at Rice University during this period. The most recent of these was published in 1992 by D. K. Walter:

Walter, D. K., Dufour, R. J., Hester, J. J. 1992, "CNO Abundances and Temperature Fluctuations in the Orion Nebula," *The Astrophysical Journal*, **397**, 196-213.

A complete list of the IUE-related publications by R. J. Dufour and collaborators is attached as Appendix A to this report. If desired, a complete list of the IUE programs that Dufour has been affiliated with can be provided upon request.

Dufour also served as a member of the IUE Users Committee during the period 1980-1983 and member of the Final Archive Definition Committee from 1986-1993.

2. Research Activity –1993 Programs

During 1993, Dufour was a Co-I on two 15th year guest observer programs:

"The Carbon Abundance of M17," (PI: M. Peimbert, Mexico) and "High Dispersion Study of BB-1," (PI: M. Peña, Mexico).

The observations of M17 were done by Co-I Silvia Torres-Peimbert and Dufour in 1993, but were unsuccessful in detecting the CIII]λ1909 needed to determine the carbon abundance in this nebula. Nonetheless, Dufour visited the Instituto de Astronomia in Mexico late that year and worked with Peimbert and Torres-Peimbert on analyzing the M17 spectra, as well as those of another Galactic HII region –M8–, for the purposes of determining the C abundance in a Sagittarius-Arm HII region for the first time. The M8 IUE SWP spectra (obtained by Dufour with the IUE several years previously) showed the CIII]λ1909 line clearly, and were combined with ground-based spectroscopy by the Peimberts to derive C/H in the Lagoon Nebula. The results were published in the paper:

Peimbert, M., Torres-Peimbert, S., and Dufour, R. J. 1993, "Chemical composition of M8 Based on IUE and Visual Observations," *The Astrophysical Journal*, **418**, 760-766.

The most notable results found for M8 were that the CNO abundances derived for it were very similar to that previously found for the Orion Nebula. This is surprising given that M8 is 2kpc closer to the Galactic Center than Orion and other studies suggested a higher CNO abundance would be expected for M8. We plan additional observations with the Hubble Space Telescope to study this matter in the future.

The second 15th year guest observer program involved IUE high dispersion observations of the Galactic halo planetary nebula BB-1. The observations were sucessfully made by the PI, M. Peña, in 1993 and published in the paper:

Peña, M., Torres-Peimbert, S., Peimbert, M., and Dufour, R. J. 1993 "IUE Observations of the Halo Planetary Nebula BB-1: the C, O, and Ne Abundances," *Revista Mexicana de Astronomia y Astrofisica*, **27**, 175-179.

The results indicated that BB-1 is among the PNe with the highest C/O and Ne/O ratios every found in such ejected shells from old stars of mass similar to the sun. This has significant ramifications regarding the chemical enrichment by PNe in the early history of the Galaxy, as well as raising new questions regarding the nucleosythesis of C, N, and Ne is PNe from Population II stars.

Also in 1993, Dufour and collaborators received data of the UV spectra of several extragalactic HII regions obtained with the *Hubble Space Telescope Faint Object Spectrograph.* Dufour lead the effort to compare the HST spectra with old- and NEWSIPS-processed IUE spectra of the same objects. The results of this comparison were published in the paper:

Dufour, R. J., Skillman, E. D., Garnett, D. R., Shields, G. A., Peimbert, M., Torres-Peimbert, S., Terlevich, E. and Terlevich, R. 1993, "Comparisons of IUE and HST Ultraviolet Spectra of Extragalactic HII Regions," *Revista Mexicana de Astronomia y Astrofisica*, **27**, 115-119.

It was found that, while the HST FOS UV spectra were of course superior to the low dispersion IUE spectra, NEWSIPS processing dramatically improved the quality of the IUE spectra in several cases. Therefore, we should expect new science to be extracted from the reprocessed spectra in the IUE archives.

3. Research Activity –1994 Programs

During 1994, Dufour and R. A. Shaw of STScI collaborated in the IUE 16th year Guest Observer Program PNPRD "Longslit IUE Spectroscopy of Planetary Nebulae," which was granted 6 shifts of IUE time. The observations were made in 1993 December (NGC 40 & NGC 3132) by Dufour and in 1994 June (NGC 3242) by graduate student Cindy M. Kurt. During both observing runs the combination of FES light leak problems and significant radiation during the US2 shifts limited the success of the observations. Originally we wanted to obtain 6-8 SWP and LWP spectra in line with the major axis of the large aperture to combine into one continuous spectrum across the nebulae. Only for NGC 3242 were we able to obtain sufficient spectra for the task. In Appendix B, we present a list of the spectra obtained for the project and a summary of the data by Ms. Kurt. A second problem that hampered completion of this program to date is that a ground-based longslit spectroscopy run with the 2.1m telescope in San Pedro Martir Observatory in Baja, Mexico during 1994 February was heavily curtailed by clouds. This prevented us from getting the desired optical spectra to compare with the IUE spectra. Nonetheless, Ms. Kurt has studied and measured all of the spectra and summarize the results in Appendix B. It is unlikely that a publication will result from this program.

However, Dufour and Shaw did collaborate on a "satellite" IUE-related program of developing an automated nebular UV-optical-IR spectrum analyzer software package to derive temperatures, densities, and ionic abundances from nebular emission line spectra data. An old 5-level atom program originally developed by Dufour was extended to include new ions (particularly with UV lines) and modernized in the atomic data employed in the analysis. Shaw incorporated the software into the IRAF/STSDAS package for general use. In addition, the new program is described in a paper that appeared in the 1995 September *PASP*:

Shaw, R. A., and Dufour, R. J. 1995, "Software for the Analysis of Emission Line Nebulae," *Publ. A.S.P.*, **107**, 896.

In the demonstration of the program, UV spectra from IUE archives are used in conjunction with ground-based visible-IR spectra of the planetary nebula IC418 and HII region SMC N88A.

Finally, Dufour spent a major part of the summer of 1994 writing the review paper ULTRAVIOLET SPECTROSCOPY, which was presented in the conference *The Analysis of Emission Lines* held in Baltimore in May 1994. In this review, he summarizes the highlights of some 16-yrs of IUE and 4-yrs of HST UV spectroscopy of nebulae, as well as the results of other space-borne instruments' observations (*e.g., ASTRO-1 HUT*). The review article appeared in a book by Cambridge University Press:

Dufour, R. J. 1995, "ULTRAVIOLET SPECTROSCOPY," in *The Analysis of Emission Lines*, eds. R. Williams & M. Livio (Cambridge: Cambridge Univ. Press), pp. 107-133.

4. Current Status and the Future

Dufour currently is working on archival IUE spectra of HII regions as part of the NASA Astrophysics Data Program. He and graduate student Kurt are studying some 300-odd NEWSIPS-processed SWP low dispersion spectra of extragalactic and Galactic HII regions in order to perform a more complete analysis of the C- and Si- abundances in such nebulae than previously possible. In addition, Dufour is a PI or Co-I on numerous HST programs related to UV spectroscopy of nebulae.

In the future, we expect to finish the IUE archival program with a publication expected to be submitted in late 1996 or early 1997. Imagery of some of the program PNPRD planetary nebulae will be attempted in mid-1996 from the Canary Is. If successful, we might be able to utilize the 1993-1994 IUE "longslit" observations in an analysis of how the UV and optical lines vary across one or more planetary nebulae.

In conclusion, grant NAG5-262, and 17 supplements, supported the majority of the IUE -related research of R. J. Dufour and several graduate students for a period of over 12 years; resulting in over 26 publications. For this, he and several former students (now Ph. D.'s) are very grateful.

APPENDIX A: IUE-RELATED PUBLICATIONS

R. J. DUFOUR ET AL.

Dufour, R. J., R. J. Talbot, Jr., and G. A. Shields, The Carbon Abundance in Two H II Regions of the Small Magellanic Cloud, *The Universe at Ultraviolet Wavelengths*, (NASA C-2171), p. 671, 1981.

Dufour, R. J., G. A. Shields, and R. J. Talbot, Jr., The Carbon Abundance in the Magellanic Clouds from IUE Observations of H II Regions, *Astrophys. J.*, **252**, 461, 1982.

Dufour, R. J. and G. A. Shields, CNO Abundances in H II Regions of the Magellanic Clouds and the Galaxy with Implications Regarding the Nucleosynthesis of the CNO Element Group, *Advances in Ultraviolet Astronomy: Four Years of IUE Research*, (NASA Conference Publication 2238), p. 385, 1982.

Dufour, R. J., The Unique Planetary Nebula NGC 2818, *Astrophys. J.*, **287**, 341, 1984.

Dufour, R. J., The Composition of H II Regions in the Magellanic Clouds, in *IAU Symp. No. 108: The Structure and Evolution of the Magellanic Clouds*, eds. S. van den Bergh, K. S. de Boer (Dordrecht: Reidel), p. 353, 1984.

Davidson, K., R. J. Dufour, N. R. Walborn, T. R. Gull, Ultraviolet and Visual-wavelength Spectrophotometry of Gas Around Eta Carinae, *Astrophys. J.*, **305**, 867, 1986.

Dufour, R. J., Abundances in Dwarf Irregular Galaxies, *Pub. Astron. Soc. Pacific*, **98**, 1025, 1986.

Dufour, R. J., D. R. Garnett, G. A. Shields, The Abundances of Carbon and Nitrogen in I Zw 18, *Astrophys. J.*, **332**, 752, 1988.

Mitra, P., R. J. Dufour, Spectrophotometry of the Shell Surrounding AG Carinae, *Monthly Notices of the Royal Astron. Soc.*, **242**, 98, 1989.

Dufour, R. J. and J. J. Hester, Extended Emission and Star Formation in IZw 18, *Astrophys. J.*, **350**, 149, 1990.

Dufour, R. J., Emission Line Nebulae in the Magellanic Clouds, in Evolution in Astrophysics: IUE Astronomy in the Era of New Space Missions, ESA SP-310, 117, 1990.

Dufour, R. J., M. L. Mulrooney, and D. K. Walter, Type I Planetary Nebulae, in *Evolution in Astrophysics: IUE Astronomy in the Era of New Space Missions*, ESA SP-310, 293, 1990.

Dufour, R. J., The CNO Nucleosynthesis Triad in Planetary Nebulae, *Pub. Astron. Soc. Pacific* **103**, 857, 1991.

Roy, J.-R., M. Aube, M. L. McCall, and R. J. Dufour, The Origin of Broad Spectral Lines in the Extragalactic H II Region NGC 2363, *Astrophys. J.*, **386**, 498 1992.

Walter, D. K., R. J. Dufour, and J. J. Hester, CNO Abundances and Temperature Fluctuations in the Orion Nebula, *Astrophys. J.*, **397**, 196, 1992.

Rubin, R. H., R. J. Dufour, and D. K. Walter, Silicon and Carbon Abundances in the Orion Nebula, *Astrophys. J.*, **413**, 242, 1992.

Peimbert, M., S. Torres-Peimbert, and R. J. Dufour, Chemical Composition of M8 Based on IUE and Visual Observations, *Astrophys. J.*, **418**, 760, 1993.

Dufour, R. J., E. D. Skillman, D. R. Garnett, G. A. Shields, M. Peimbert, S. Torres-Peimbert, E. Terlevich, and R. Terlevich, Comparison of IUE and HST Ultraviolet Spectra of Extragalactic HII Regions, *Rev. Mexicana Astron. Astrofísica* , **27**, 115 1993.

Peña, M., S. Torres-Peimbert, and R. J. Dufour, IUE Observations of the Halo Planetary Nebula BB-1: The C, O, and Ne Abundances, *Rev. Mexicana Astron. Astrofisica*, **27**, 175, 1993.

Walter, D. K., and R. J. Dufour, Anomalous Balmer Continuum Temperatures in the Orion Nebula, *Astrophys. J. Letts.*, **434**, L29, 1994.

Dufour, R. J., HII Regions as Cavities, *Rev. Mexicana Astron. Astrofisica*, **29**, 88, 1994.

Dufour, R. J., Wolf-Rayet Shell Nebulae, in *Circumstellar Media in the Late Stages of Stellar Evolution*, eds. Clegg, R. E. S. et al. (Cambridge: Cambridge Univ. Press), pp. 78-84, 1994.

Garnett, D. R., E. D. Skillman, R. J. Dufour, M. Peimbert, S. Torres-Peimbert, R. Terlevich, and E. Terlevich, The Evolution of C/O in Dwarf Galaxies from HST FOS Observations, *Astrophyhs. J.*, **443**, 64, 1995.

Dufour, R. J., Ultraviolet Spectroscopy, in the *Analysis of Emission Lines,* eds. R. Williams and M. Livio (Cambridge: Cambridge Univ. Press), pp. 107-133, 1995.

Shaw, R. A., and R. J. Dufour, Software for the Analysis of Emission Line Nebulae, *Publ. Astron. Soc. Pacific,* **107**, 896, 1995.

APPENDIX B: INFORMATION RELATED TO 15TH YEAR GO PROGRAM "PNPRD"

B.1. List of Spectra Obtained (1993-1994)

IUE LOG Database (up to 12-Mar-1996)

IUE cam nam	IUE image number	d i s	a p t	exp num	object name	IUE obj cl	R.A. 1950 hh	mm	ss.ss	Dec. 1950 dd	mm	ss	obs yr	obs day	FA st fl
LWP	27070	L	L	1	NGC 3132	71	10	04	54.79	-40	11	39	93	353	Z
LWP	27075	L	L	1	NGC 40	70	00	10	16.49	+72	14	38	93	354	Z
LWP	27076	L	L	1	NGC 40	71	00	10	16.20	+72	15	54	93	354	Z
LWP	27077	L	L	1	NGC 40	71	00	10	17.00	+72	15	44	93	355	Z
LWP	28448	L	L	1	NGC 3242	70	10	22	21.50	-18	23	23	94	170	W
LWP	28449	L	L	1	NGC 3242-NEB	71	10	22	21.70	-18	23	12	94	170	W
LWP	28450	L	L	1	NGC 3242-NEB	71	10	22	21.80	-18	23	03	94	170	W
LWP	28451	L	L	1	NGC 3242-NEB	71	10	22	21.99	-18	22	53	94	170	W
LWP	28451	L	S	2	NEAR NGC 324	71	10	22	22.17	-18	23	34	94	170	W
LWP	28459	L	L	1	NGC 3242	71	10	22	21.19	-18	23	42	94	171	W
LWP	28460	L	L	1	NGC 3242	71	10	22	21.29	-18	23	31	94	171	W
LWP	28461	L	L	1	NGC 3242	71	10	22	21.80	-18	23	03	94	171	W
LWP	28462	L	L	1	NGC 3242	71	10	22	21.70	-18	23	12	94	171	W
LWP	28464	L	L	1	NGC 3242	71	10	22	21.70	-18	23	12	94	172	W
LWP	28465	L	L	1	NGC 3242	70	10	22	21.50	-18	23	23	94	172	Z
LWP	28466	L	L	1	NGC 3242	71	10	22	21.80	-18	23	03	94	172	W
LWP	28467	L	L	1	NGC 3242	71	10	22	21.19	-18	23	42	94	172	Z
LWP	28467	L	S	2	NEAR NGC 324	71	10	22	21.31	-18	24	23	94	172	Z
SWP	49627	L	L	1	NGC 3132-CEN	70	10	04	55.80	-40	11	28	93	353	I
SWP	49628	L	L	1	NGC 3132	71	10	04	54.79	-40	11	39	93	353	Z
SWP	49629	L	L	1	NGC 3132EMIS	71	10	04	54.49	-40	11	48	93	353	I
SWP	49630	L	L	1	NGC 3132EMIS	71	10	04	55.60	-40	11	08	93	354	I
SWP	49631	L	L	1	NGC 3132EMIS	70	10	04	55.30	-40	11	18	93	354	I
SWP	49635	L	L	1	NGC 40	71	00	10	15.60	+72	14	50	93	354	Z
SWP	49636	L	L	1	NGC 40	71	00	10	14.69	+72	15	02	93	354	Z
SWP	49637	L	L	1	NGC 40	70	00	10	18.30	+72	14	15	93	355	Z
SWP	49638	L	L	1	NGC 40	71	00	10	17.39	+72	14	27	93	355	Z
SWP	51132	L	L	1	NGC 3242	70	10	22	21.50	-18	23	23	94	170	W
SWP	51133	L	L	1	NGC 3242-NEB	71	10	22	21.70	-18	23	12	94	170	W
SWP	51134	L	L	1	NGC 3242-NEB	71	10	22	21.80	-18	23	03	94	170	4
SWP	51135	L	L	1	NGC 3242-NEB	71	10	22	21.99	-18	22	53	94	170	W
SWP	51144	L	L	1	NGC 3242	71	10	22	22.10	-18	22	42	94	171	W
SWP	51144	L	S	2	NEAR NGC 324	71	10	22	22.30	-18	23	22	94	171	W
SWP	51145	L	L	1	NGC 3242	71	10	22	20.89	-18	24	01	94	171	W
SWP	51146	L	L	1	NGC 3242	71	10	22	21.29	-18	23	31	94	171	W
SWP	51147	L	L	1	NGC 3242	71	10	22	21.70	-18	23	12	94	171	W
SWP	51148	L	L	1	NGC 3242	71	10	22	20.99	-18	23	51	94	171	W
SWP	51150	L	L	1	NGC 3242	71	10	22	21.70	-18	23	12	94	172	W
SWP	51151	L	L	1	NGC 3242	71	10	22	21.70	-18	23	12	94	172	Z
SWP	51152	L	L	1	NGC 3242	71	10	22	21.18	-18	23	42	94	172	U
SWP	51153	L	L	1	NGC 3242	71	10	22	21.80	-18	23	03	94	172	Z
SWP	51154	L	L	1	NGC 3242	70	10	22	21.50	-18	23	23	94	172	Z
SWP	51155	L	L	1	NGC 3242	70	10	22	21.50	-18	23	23	94	172	Z
SWP	51156	L	L	1	NGC 3242	71	10	22	21.29	-18	23	31	94	172	Z

B.2. - Summary of Observational Results for PNPRD

The original proposal for IUE GO program PNPRD consisted of obtaining low dispersion SWP and LWP spectra of PNe's NGC 40, NGC 3132, NGC 3242, and NGC 7662, with overlapping large aperture long axes, to study the continuous variations in prominent UV lines across the nebulae. Dufour acquired spectra of NGC 40 and NGC 3132. Kurt obtained spectra of NGC 3242. No spectra of NGC 7662 were taken.

NGC 40: 3 LWP and 4 SWP spectra were taken at various positions across the nebula. Some lines found are: 1335/36 CII, 1548/50 CIV, 1658-1666 [OIII], 1747-54 [NIII], 1892 [SiIII], 1907/09 [CIII], 2334-2350 [SiIII], 2837/38 CII, 2929 MgV, 3133 OIII.

NGC 3132: 1 SWP and 1 LWP spectra are available. Four other SWP spectra are listed for program PNPRD, but the data files do not exist. Some lines found are: 1548/50 CIV, 1640 HeII, 1658-1666 [OIII], 1747-54 [NIII], 1882 [SiIII], 1907/09 [CIII], 3133 OIII.

NGC 7662: No spectra were taken. (For both the first and second shifts, meaningful spectra were not taken until two hours into the shift. The first day NGC 3242 could not be found until 11:10 AM. The second day a 60 min. exposure was ended at 40 min. due to a large spacecraft drift. It was determined that the remaining time in the second shift and the third shift would be used to try to obtain as complete a set of exposures for NGC 3242 as possible. Recall that the goal was optimal and 4-5X over-exposed spectra for each of 9 positions along the long axis of the nebula.)

NGC 3242: 12 LWP and 14 SWP spectra were taken. Two other SWP spectra are listed for program PNPRD, but the data files do not exist. Good spectra (SWP and/or LWP) were obtained for the 5 innermost regions. The spectra for the 4 outermost regions are underexposed. Some lines found at the various positions are: 1483/87 [NIV], 1575 [NeV], 1640 HeII, 1658-1666 [OIII], 1747-54 [NIII], 1907/09 [CIII] 1760 CII, 1907/09 [CIII], 2423/25 [NeIV], 2837/38 CII, 3043/47 OIII, 3133 OIII, 3203 HeII.

Note that most of the FWHM for these lines are large: >8 A, so the identification of some of the lines may be incorrect.

FOLLOWING PAGES ARE FIRST PAGES OF VARIOUS PUBLICATIONS CITED IN REPORT.

THE ASTROPHYSICAL JOURNAL, 397:196–213, 1992 September 20

CNO ABUNDANCES AND TEMPERATURE FLUCTUATIONS IN THE ORION NEBULA

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ABSTRACT

Abundances of carbon, nitrogen, and oxygen in 22 regions of the Orion Nebula are derived using diagnostic emission lines measured from *IUE* and ground-based spectrophotometry and imagery. In order to minimize geometrical complications, the regions chosen lie in the relatively smooth area of the nebula west of the Trapezium and extend outward to about 5′. For 20 of the regions, both C III] λ1909 and C II] λ2326 were measured from the *IUE* spectra, and combined with optical line strengths of [O II], [O III], [N II], Hβ, and Hα to study spatial variations in the ionic and total elemental concentrations of C, N, and O.

A detailed analysis of UV-optical extinction, temperature gradients, and density gradients using new and previously reported observations is given. Empirical CNO abundances are derived for each position using both on-the-spot values for T_e (from [O III] and [N II]) and N_e (from [S II]), as well as global mean values for the nebula. For both situations of T_e-N_e gradients and an isothermal nebula we find no evidence of the existence of radial gradients in C, N, or O westward from the Trapezium (within $\pm$0.2 dex rms). However, the mean concentrations of C, N, and O relative to H found using directly observed temperatures are much lower than solar; in terms of 12 + log (X/H) we derived (C, N, O) = (7.94, 7.50, 8.45).

Rather than conclude that the Orion Nebula is depleted in CNO compared to the Sun, we propose the existence of significant temperature fluctuations in the nebula. For such, the auroral transitions of the [O III] and [N II] multiplets are enhanced by a hotter medium (possibly wind-driven or shock-ionized) compared to the mass-loaded and denser regions which emit the bulk of the nebular transitions. We show that an assumed rms temperature fluctuation of 0.055 gives abundances of (C, N, O) = (8.78, 7.73, 8.90), where the oxygen is solar and, within our error bars, the carbon is near solar.

Additional support for Orion having near-solar abundances comes from the results of a grid of constant-density nebular models based on a single ionizing source with $T_{\rm eff}$ = 37,500 K (similar to θ^1 Ori C). We find that the "mean" UV-optical spectrum of a "core" region $\sim$1′ W of the Trapezium can be readily matched with a model of solar O, N, Ne, and S with enhanced C and Ar. The lower temperatures found in such a model are consistent with a rms temperature fluctuation of 0.055. We compare our simple model results with more sophisticated "blister" and "dust" models of M42 published recently and discuss some of the implications that the complications of Orion have with regard to the greater problem of abundance determinations in Galactic and extragalactic H II regions.

Subject headings: H II regions — ISM: abundances — ISM: individual (Orion Nebula) — ultraviolet: interstellar

1. INTRODUCTION

The Orion Nebula (NGC 1976, M42) is undoubtedly the most observed H II region in the sky. Its large angular extent and high surface brightness have made it the subject of numerous observational and theoretical studies over the years (cf. Goudis 1982; Glassgold, Huggins, & Schucking 1982, and references therein). Orion is important not only to our understanding of H II regions, but also as a standard of comparison for other objects (cf. The recent review by Shields 1990). The chemical makeup of M42 is used as a point of reference when comparing abundances of the Sun, Galactic H II regions, planetary nebulae, and extragalactic systems such as the SMC and LMC. In fact, it is as important to the understanding of gaseous nebulae as the Sun is to our understanding of other stars. Important studies of Orion go back many years and include works in the optical by Peimbert & Costero (1969) and Peimbert & Torres-Peimbert (1977, hereafter PTP). Studies in the UV include Perinotto & Patriarchi (1980), Torres-Peimbert, Peimbert, & Daltabuit (1980), along with modeling by Dufour, Shields, & Talbot (1982) and Mathis (1985). More recently Baldwin et al. (1991, hereafter BFMCCPS) and Rubin et al. (1991, hereafter RSHE) have broken new ground in our understanding of the modeling of the Orion Nebula, while Osterbrock, Tran, & Veilleux (1992) have examined some of the rarer elements present in the nebula. Exciting new observa-

[1] Guest Observer, *International Ultraviolet Explorer Satellite*, which is sponsored and operated by the National Aeronautics and Space Administration, the European Space Agency, and the Science and Engineering Research Council of the United Kingdom.

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CHEMICAL COMPOSITION OF M8 BASED ON *IUE* AND VISUAL OBSERVATIONS

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ABSTRACT

We present optical and *IUE* observations of the Hourglass Nebula which is embedded in the galactic H II region M8. By comparing the intensities of the C III] lines λλ1907 + 1909 with that of C II λ4267, a value of $t^2 = 0.046 \pm 0.01$ is obtained. The logarithmic abundances by number of the gaseous component for $t^2 = 0.046$ are: H = 12.00, He = 11.00 C = 8.55, N = 7.80, O = 8.74, Ne = 7.99, S = 7.38, Ar = 6.76, and Fe = 6.16. These abundances are compared with those of other galactic H II regions, the Sun, and B stars of the solar neighborhood.

Subject headings: H II regions — ISM: abundances — ISM: individual (M8) — ultraviolet: interstellar

1. INTRODUCTION

The Hourglass Nebula (hereafter HG) is the brightest region of the galactic H II region Messier 8 (also known as NGC 6523, S25, W29, and the Lagoon Nebula). After the Orion Nebula, M8 is probably the most studied galactic H II region in the visual. The H II region forms a blister on the surface of a giant molecular cloud that is located behind the H II region (e.g., Lada et al. 1976; Lynds & O'Neil 1982).

There are only two galactic H II regions with accurate determinations of the mean square temperature fluctuation over the observed volume, t^2, and the C/H abundance ratio in the literature: the Orion Nebula and M17 (Torres-Peimbert, Peimbert, & Daltabuit 1980; Walter, Dufour, & Hester 1992; Peimbert, Torres-Peimbert, & Ruiz 1992; Peimbert, Storey, & Torres-Peimbert 1993). We decided to add the Hourglass Nebula to this list by comparing collisionally excited lines of C II] and C III] in the UV region with a recombination line of C II in the visual region.

From the ratio of the [C III] λ1907 and C III] λ1909 line intensities to that of C II λ4267, it is possible to determine t^2 and use it to estimate the temperature structure of a nebula necessary for deriving accurate abundances. From these carbon lines and the Balmer lines it is also possible to obtain an accurate C/H value.

In § 2 we present the optical and *IUE* observations; in § 3, the physical conditions; in § 4, the abundances; and in § 5, the comparison of the abundances with those derived from other galactic H II regions, the Sun, and B stars of the solar neighborhood.

2. OBSERVATIONS

2.1. *Optical*

The optical observations were carried out during May and September 1978 with the Gold spectrograph and the intensified image dissector scanner (IDS) at KPNO. Part of the May observations were reported before (Sánchez & Peimbert 1991, hereafter SP; see also Sánchez & Peimbert 1993), but they have been reanalyzed here and the September observations have been incorporated. The entrance slit used was 0.30 × 0.98 mm oriented east-west and corresponds to 3."8 × 12."4 on the plane of the sky. Two gratings were used which covered the following wavelength ranges: λλ3400–5200 and λλ5600–7400. The spectral purity (FWHM of the emission lines) was ≈6.7 Å.

The center of the observed region, M8 HG, is located 14" south and 17" east of Herschel 36 (H36) (12" south of the "waist" of the HG; see Woodward et al. 1986)). The data were reduced to absolute fluxes using the standard stars observed by Stone (1977) and Oke (1974) and have been corrected for the nonlinearity of the detector by considering that the flux F is related to the instrumental signal S by

$$S \propto F^{1.07} . \tag{1}$$

(Peimbert & Torres-Peimbert 1987). In Table 1 we present the intrinsic line intensities in ergs cm^{-2} s^{-1}, $I(\lambda)$, relative to $I(\mathrm{H}\beta)$ given by

$$\log [I(\lambda)/I(\mathrm{H}\beta)] = \log [F(\lambda)/F(\mathrm{H}\beta)] + C(\mathrm{H}\beta)g(\lambda) , \tag{2}$$

where $F(\lambda)$ is the observed line flux corrected for atmospheric extinction, $C(\mathrm{H}\beta)$ is the logarithmic reddening correction at Hβ, and $g(\lambda)$ is the reddening function normalized at Hβ. H36 has been found to be the main star responsible for the ionization of the HG (e.g., Woodward et al. 1986; SP, and references therein). Representative spectra of M8 HG have been presented in SP. For H36 the $A_V/E(B-V)$ ratio, R, has been determined as 4.6 (Hecht et al. 1982) and as 5.3 (Mathis 1990). Consequently, we will adopt a reddening function for $R = 5.0$ presented by Mathis to correct the M8 HG observations.

A $C(\mathrm{H}\beta)$ value of 1.00 ± 0.1 was obtained by fitting the observed Hγ/Hβ and Hδ/Hβ ratios to the theoretical ones computed by Hummer & Storey (1987) for $N_e = 1000$ cm^{-3} and $T_e = 8000$ K; the Balmer decrement is almost insensitive to N_e and T_e for the range of expected values. Since the blue and the red part of the spectrum were not observed simultaneously, the $I(\mathrm{H}\alpha)/I(\mathrm{H}\beta)$ ratios were adjusted to the theoretical one by applying a grayshift correction to the red part of the spectrum. The average grayshift was ≈0.05 dex and it is mainly due to small displacements of the entrance slits. In Table 1 the 1 σ error in the last digit is presented after each measurement (i.e., the first intensity ratio is 0.34 ± 0.02 dex); the errors were estimated by comparing the results derived from the two different seasons. Log $F(\mathrm{H}\beta)$ is equal to

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IUE OBSERVATIONS OF THE HALO PLANETARY NEBULA BB-1: THE C, O AND Ne ABUNDANCES

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RESUMEN

Presentamos nuevas observaciones con el satélite IUE en alta y baja dispersión de la nebulosa planetaria del halo BB-1 (PN G108.4 -76.1). Hemos determinado que el valor de C/H es 5.1×10^{-4}. Este objeto está entre las nebulosas planetarias con los cocientes más altos de C/O y Ne/O; su cociente Ne/O es 10 veces mayor que el solar. El enriquecimiento extremo de C y Ne impone condiciones muy estrictas sobre los modelos de evolución estelar de estrellas de baja masa.

ABSTRACT

We present new high and low dispersion IUE observations of the halo planetary nebula BB-1 (PN G108.4 -76.1). We have determined the C/H value to be 5.1×10^{-4}. This object is among the PNe with the highest C/O and Ne/O ratios; its Ne/O ratio is 10 times higher than solar. The extreme enrichment of C and Ne imposes strong constraints on stellar evolution models of low-mass stars.

Key words: **ISM: ABUNDANCES — PLANETARY NEBULAE: GENERAL**

1. INTRODUCTION

Halo stars are expected to have low mass and extreme metal deficiency. The study of halo PNe can provide information about the ejection process of the nebular material, the evolution of Population II stars and the abundances of elements in the early chemical history of the Galaxy. Determinations of the chemical composition of the nebular material allow us to derive the initial chemical composition of the elements that do not change during nuclear processes in intermediate mass stars – such is expected to be the case for Ar, S, and Si. While from the study of the elements altered by stellar nucleosynthesis, like N and C, we can understand better the different evolutionary episodes within the progenitor star (Peimbert 1992; Renzini 1989).

The known sample of extreme Population II PN is limited to H4-1, BB-1, K 648, M2-29 and GJJC-1 and there are other 5 objects identified as belonging to the thick galactic disk. There are several abundance studies on BB-1 in the literature (Barker 1980; Torres-Peimbert et al. 1981, 1990; Peña et al. 1991, hereinafter PTPR91) and there has been a considerable effort to determine the chemical abundances of all halo PNe (e.g., Peña et al. 1989, 1990, 1991; Torres-Peimbert et al. 1990). Several of the extreme halo PN are underabundant in S and Ar relative to solar values by about two orders of magnitude and underabundant in O and Ne by about one order of magnitude. Two possibilities have been discussed in the literature to explain the different underabundances: a) that the enrichment of O and Ne in the interstellar medium has proceeded faster than that of Ar and S; and b) that the O and Ne excesses relative to Ar and S were produced by their progenitors

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COMPARISONS OF IUE & HST ULTRAVIOLET SPECTRA OF EXTRAGALACTIC HII REGIONS[1]

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RESUMEN

Comparamos espectros HST FOS recientemente obtenidos con espectros ultravioleta IUE SWP de dos regiones HII extragalácticas: SBS 0335-052 y 30 Doradus en la Nube Mayor de Magallanes. Los espectros FOS se tomaron usando la configuración G190H/RD y apertura circular de 1.0 segundo de arco; cubren el intervalo de longitud de onda 1570-2310 Å . Los espectros IUE son exposiciones SWP de baja dispersión tomadas con la apertura grande ovalada de ~10″x20″; cubren el intervalo de 1150-2000Å . A pesar de la mucho menor apertura en HST FOS, los espectros HST son superiores a los espectros de baja dispersión IUE SWP (procesados en forma estándar) en cuanto a S/R para las líneas de emisión ultravioletas debido al mayor intervalo dinámico y la mayor resolución en longitud de onda del FOS. Sin embargo presentamos espectros IUE SWP de I Zw 18, procesados mediante NEWSIPS, cuyos datos muestran mejoras en las calidad que sugieren la posibilidad de incrementar de manera importante los resultados científicos mediante el reprocesamiento del acervo de espectros IUE.

ABSTRACT

We compare recently obtained HST FOS and IUE SWP ultraviolet spectra of two extragalactic HII regions: SBS 0335-052 and 30 Doradus in the LMC. The FOS spectra were taken using the G190H/RD configuration and the 1.0 arcsec diameter circular aperture and cover 1570-2310Å . The IUE spectra are low-dispersion SWP exposures taken through the ~10″x20″ oval large aperture and cover 1150-2000Å . Despite the much smaller HST FOS aperture, the HST spectra are superior to the (standard processed) low-dispersion IUE SWP spectra in S/N for the UV emission lines due to the larger dynamic range and wavelength resolution of the FOS. We also present IUE SWP NEWSIPS processed spectra of I Zw 18, which show significant improvements in the data quality, suggesting that reprocessed IUE archival spectra will offer enhanced science for the future.

Key words: **H II REGIONS — GALAXIES: IRREGULAR — ULTRAVIOLET: GALAXIES**

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Software for the Analysis of Emission-Line Nebulae

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ABSTRACT. A set of software tools has been developed for the IRAF/STSDAS environment to derive the physical conditions in a low-density (nebular) gas given appropriate diagnostic emission-line ratios; and line emissivities given appropriate emission-line fluxes, the electron temperature (T_e) and density (N_e). The package is based on the five-level atom program developed by De Robertis et al. (JRASC, 81, 195, 1987), but it includes diagnostics from a greater set of ions and emission lines, most particularly those in the satellite ultraviolet that are now observable. Two of the applications make use of a three-zone nebular model to derive T_e and N_e simultaneously in separate zones of low-, intermediate-, and high-ionization. These applications are useful for calculating nebular densities and temperatures directly from the traditional diagnostic line ratios, either to provide some reasonable input parameters for a more complicated physical model, or to calculate ionic abundances (or other quantities) within some simplifying assumptions. Examples of the utility of these diagnostics for real nebulae are presented.

1. INTRODUCTION

The interpretation of emission-line radiation from an ionized gas is important in a wide variety of astrophysical contexts, such as H II regions, planetary nebulae, active galactic nuclei, and nova and supernova remnants. The physical basis for line emission from a photoionized nebula has been well understood for decades, and is discussed in many excellent references (see, e.g., Osterbrock 1989; Aller 1984). It turns out that most of the common ions that dominate the nebular cooling rate have ground-state electron configurations with five low-lying levels. To fair approximation, only these five levels are relevant to calculating the observable emission-line spectrum for a given ion. Transitions between these five levels span the range from the satellite ultraviolet to the infrared, and all are now observable with a combination of ground-based and space-based observing facilities.

It is relatively straightforward within this five-level atom approximation to solve the equations of statistical equilibrium (see Sec. 2.1) to obtain the level populations and line emissivities. Certain ratios of these line emissivities are particularly good indicators of electron temperature (T_e) or density (N_e) (see Sec. 2.2), and one can employ an iterative technique to match an observed line ratio to that computed for a given T_e and N_e. Such a technique was developed by De Robertis et al. (1987, hereafter DDH), who published a FORTRAN algorithm to derive N_e and T_e for a large number of commonly used diagnostic line ratios. Using several such diagnostics from ions with different ionization potential allows one to infer a simple physical model for an observed nebula, from which one can drive ionic abundances.

We developed a package of applications (tasks) for the IRAF/STSDAS environment to derive the physical conditions in a low-density (i.e., nebular) gas given appropriate diagnostic emission-line ratios; and line emissivities given appropriate emission-line fluxes, the electron temperature and density. Most tasks in this package, called **nebular**, are based on the FIVEL program developed by DDH, who described the equations to be solved and their method of solution. These tasks extend the functionality of the original FIVEL program, and also provide a very simple model within which to derive the nebular ionic abundances. These tasks are most useful in the fairly common instances where one desires to calculate nebular densities or temperatures directly from the traditional diagnostic line ratios, either to provide some reasonable input parameters for a more complicated physical model, or to calculate ionic abundances (or other quantities) within some simplifying assumptions.

The major reason to build this software was our need to analyze the physical conditions and ionic abundances for a large number (>100) of nebulae relatively quickly to support an archival research program. For almost all the nebulae in that program, we used a combination of spectra from the *IUE* and *HST* archives, and/or fluxes published in the literature. As such, the data are often incomplete in the sense that only a few diagnostics may be available, and they may be different from one nebula to the next, depending upon the quality and extent of the observations, and upon the excitation level of the nebula. In cases where the data are sparse, it may not be possible to construct a very complete physical model, beyond an average temperature and density; in other cases a very detailed model may be in order, in which case we look to the traditional diagnostics as a starting point.

We chose to build upon the FIVEL library because it was fairly straightforward to do, and because it contained much of the functionality we needed. However, the user interface was rather awkward, and was very inefficient for analyzing potentially dozens of diagnostics in each of over one hundred nebulae. We chose to port this application to the IRAF/STSDAS environment in order to provide a simple,

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ULTRAVIOLET SPECTROSCOPY

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ABSTRACT

A review of the field of astronomical ultraviolet spectroscopy with emphasis on *emission lines* in astrophysical plasmas is presented. A brief history of UV spectroscopy instruments is given, followed by a discussion and tabulation of major atlases of UV emission-line objects to date (mid-1994). A discussion of the major diagnostic UV emission lines in the ~ 912-3200Å spectral region that are useful for determining electron densities, temperatures, abundances, and extinction in low- to moderate-density plasmas is given, with examples of applications to selected objects. The review concludes by presenting some recent results from HST, HUT, and IUE on UV emission-line spectroscopy of nebulae and active galaxies.

I. INTRODUCTION

The history of ultraviolet (UV) spectroscopy in astronomy spans over three decades now and such observations have led to many discoveries regarding the physical nature of the entire gambit of astronomical objects. Hot astrophysical plasmas have line and continuum emission and absorption processes for which UV spectroscopy can probe the more energetic physical processes that cannot be studied adequately in the optical or infrared. In addition, studies of the UV spectral properties of cooler bodies, such as planetary atmospheres, comets, and interstellar dust provide important information on their physical state and composition.

This article concentrates on reviewing some of the techniques and results from the study of *emission lines* in astronomical UV spectroscopy. Given that the range of astronomical objects from the Earth's geocorona to quasars show UV emission lines and that during the past three decades over two thousand papers have appeared in the literature, including numerous conferences and books, a comprehensive review is unpractical. Therefore, the author will limit this discussion to a review of the various emission-line diagnostics present in UV spectra from approximately the Lyman Limit (912Å) to near the atmospheric cutoff (3200Å). In addition, he will concentrate on recent results during the past few years obtained with the International Ultraviolet Explorer (IUE), the Hubble Space Telescope (HST), and the Hopkins Ultraviolet Telescope (HUT) flown on the 1991 Astro-1 space shuttle mission. Readers who wish to obtain a more comprehensive review of the observations and scientific results from UV spectroscopic studies across the entire repertoire of astronomical objects should began with a study of the book ***Exploring the Universe with the IUE Satellite*** (Kondo 1987), which contains 36 review articles on UV spectroscopic results for all types of astronomical objects, as well as discussions on the history and future promise of astronomical UV studies.